Colors from Ceylon: A design exhibit of sustainable textiles dyed with coconut husk waste.

by

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Abstract

Inheriting tradition is an aspect of slow design that explores ways to sustain lost art and tradition. Even though natural dyeing was heavily practiced in Sri Lanka, most of the country's textile and craft industry has diverted to using synthetic dyes that are bad for the environment. Many domestically used coconut husks in Sri Lanka are thrown away as waste which can be used as a source of natural dyes for textiles.

The purpose of this study was to explore the dyeing potential and surface design possibilities of coconut (*Cocos nucifera*) husk fiber, a traditional dye source of Sri Lanka. A practice-based design approach was utilized for the project with weekly analysis and reflection on the collected data to move the design process forward. The research was conducted in four stages: dye experimentation, print design exploration, textile art, and exposition.

Coconut husks were boiled in water to extract the dyes. Four pre-treatment methods such as aluminum acetate, gallnut, pomegranate, and henna were used for cellulose and potassium aluminum sulfate was used for silk fabrics to enhance the bond between fiber and dye. To increase the color range, iron and citric acid were used as post-treatments. The leftover dye bath was recycled to separate the pigment from the water to create a thickened dye paste that could be used to create surface prints.

All the fabrics dyed in a pink beige color with slight hue variations except for the fabrics that were pretreated with henna which turned out to have a yellow cast or nude color. During post-treatment iron-treated swatches had a greyish tone and citric acid treatment turned the swatches to a pale orange shade. The thickened dye paste consistency worked best with screen-printing leaving clear lines around the edges of the prints. Based on the findings, a collection of artifacts was developed in the form of textile art. The process and outcomes of the study were

displayed in a gallery exhibit to create awareness of the craft of natural dyeing and promote using coconut husk waste as a sustainable dye option.

All the selected fabrics performed well in the evenness of dye uptake and saturation between all the pre and post treatment methods and surface printing quality. There was no color loss after hand washing indicating appropriate dye concentration and good dye to fiber bond. Therefore, coconut husk waste can be considered a good source of natural dye. The exposition served its purpose in promoting public recognition and developing public knowledge in the use of coconut husks to produce natural dyes.

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Introduction

Everything we consume influences the environment, from food and water to the clothes we wear. Clothing is an integral part of human society (Gupta & Saini, 2020). Industrialization has led to easy availability of cheaper goods (Gupta & Saini, 2020) which results in higher consumption, pollution, and waste. The more clothes people buy, the more pollution it creates. Hence, it is important to understand the urgency of sustainable ways of creating clothing, slowing down production and consumption.

Fashion products can be classified as fast and slow. The concept of fast fashion is highly appealing to many consumers who like to change their fashion style frequently (Nayak et al., 2019), thus compromising sustainable production. However, slow fashion (a process using sustainable production methods and greener technologies) meets the expectations of social responsibility and environmental sustainability (Nayak et al., 2019). Thus, products created through slow design processes contribute to sustainable development (Faud-Luke, 2005).

Textile and fashion production have a negative impact on the environment. Until the invention of synthetic dyes in 1856, textiles were dyed with natural dyes. Since then, the use of synthetic dyes has dominated the textile industry. Most of the synthetic colorants are being manufactured from petrochemical sources through hazardous chemical processes. Hence, it poses a great threat to the environment (Alam et al., 2020). Twenty percent of industrial water pollution comes from textile treatments and dyes (Lakwal, 2014). However, the current shift to a more responsible agenda in the fashion industry will see naturally derived color playing a bigger part in the product strategies of the future (Naturally derived color., n.d).

Since I was young, I maintained a keen interest in different types of aesthetic subjects which made me choose being a designer as my career aspiration. After completing high school in Sri Lanka, I went to England to pursue a bachelor's degree in Design at the University of the Arts, London. Upon returning home, combining my creativity with the knowledge and experience gained in England, I started working for a leading fashion retail brand in the country as a creative display designer, which inspired me to study more about the fashion field that led me to work as a fashion designer. During my time as a fashion designer, I volunteered as a design mentor at an arts and craft development program for traditional artisans to help transform them into entrepreneurs. This experience confirmed my long-term goal of starting my own fashion brand that would collaborate with crafts people to empower the traditional craft industry.

Natural dyeing of textiles has fascinated me over the past few years and my journey into natural dyeing began from a place of curiosity. Even though natural dyeing has been used in Sri Lanka many centuries ago it is fairly new to the country now because of its decline in use after synthetic dyes took over. This made me want to learn about natural dyes and reintroduce the age-old technique back into craft practice. Although there are a few universities that provide fashion design bachelor's degrees in my country, none of them offer the opportunity to study and specialize in innovative and sustainable techniques in-depth. Therefore, at first, I tried to learn about natural dyeing techniques on my own by reading papers, watching online tutorials, and talking to local artisans who have worked with natural dyes in the past. The discussions I had with some of the artisans made me realize that they do not want to work with natural dyes anymore because there is no demand in the market for the time and effort they put into their work. I understood that this could be because they don't have the proper exposure and ability to reintroduce the craft to the modern market. Therefore, I knew I had to get hands-on experience and knowledge about the subject so that it would help me one day to start my own sustainable fashion brand and help the local artisans.

As a student in the fashion field and more-so, a student who is researching techniques and ways for the fashion industry to be more sustainable, I believe it is an obligation and a privilege to help empower people to the best of my ability. The best I can do involves understanding my own attributes as a human, designer, and researcher, knowing what limitations I inherently face and believing in my ability and credibility to address such complex issues. I believe sustainability could be the future for fashion because it offers individuals and brands an opportunity to reimagine their work to ensure that it has a positive impact on people and the planet. My passion towards doing something useful with the knowledge and experiences I have gained throughout my academic and professional career has been the biggest motivation for me to research sustainable ways of designing clothes. Therefore, I believe this research project contributes to achieving my long-term goals.

Purpose and Objectives

My overarching long-term goals are to shift my fashion brand to a sustainable brand while also creating awareness and reintroducing the traditional craft of natural dyeing in Sri Lanka, minimize the environmental footprint in the fashion industry by incorporating sustainable design methods, and provide livelihood opportunities for Indigenous artisans through entrepreneurial development to help preserve skills. The purpose of this study was to explore the dyeing potential and surface design possibilities of coconut (*Cocos nucifera*) husk fiber, a traditional dye source of Sri Lanka. The findings from the exploration informed textile designs and the outcomes were displayed in a gallery exhibit. The objectives of this project were as follows:

1. Dye Experimentation. To generate a color palette by experimenting with pre- and post-treatments on a range of fabrics and immersion dyeing in coconut husk dye baths.

2. Print Design Exploration. Experiment with dye thickening methods and surface design techniques.

3. Textile Art. Based on best practices from the dye and print exploration, textiles were dyed and printed.

4. Exposition. The design process and textile art were exhibited at a public venue to create awareness of the craft of natural dyeing and promote natural dyeing as an alternative to synthetic dyeing.

Justification

Even with the mass production we have today, small-scale handcraft techniques still hold an important place in the fashion industry (Black, 2008). The handicraft industry in Sri Lanka has a long history (Ekanayake et al., 2020) which in recent years has been declining (Daskon, 2010) due to globalization, mass production, cheaper prices, and synthetic dyes. WGSN Future Innovations 2023 report indicates that decolonized thinking will reshape culture and business, causing brands to lean into the design of craft (WGSN forecast team, 2020). This will open many possibilities for the craft industries in developing countries to build partnerships with western brands and portray cultural heritage in an authentic way.

Coconut husk is easily obtained at minimal to no cost in Sri Lanka. With the resurgence of natural dye in the textile industry (Naturally derived color., n.d), I believe coconut husk fiber could be an economical and sustainable dye option. While research has been conducted on the colorfastness and dyeing potential of coconut husk (Adeel et al., 2020; Kashyap et al., 2016; Kholil et al., 2021; Sahara et al., 2019; Samant & Gaikwad, 2020), design possibilities of the extracted dyes was not found in the research to produce fashionable textiles and garments. At the same time, for many rural communities, recognition, and support for the realization of the potential of their own culture and traditional values will be critical in attaining livelihood security and sustainability (Teo et al., 2020). Natural dyes and colorants are an essential part of the world's ecological and cultural heritage (Cardon, 2010). Therefore, the outcomes of this study extend the use of coconuts to textile design as an initial step in reintroducing the age-old craft of natural dyeing and contribute to the sustainable development of the craft industry in Sri Lanka.

Contextual Review

Background

Natural Dyes

In the field of apparel manufacturing, there are two broad categories for dyes: natural and synthetic. Natural dyes come from natural sources such as plants, flowers, vegetables, insects, or minerals, but can also be harvested from mollusks, lichens, and mushrooms (Boutrup & Ellis, 2018). The history of natural dye is more than 4,000 years old, and much information has been passed through generations (Cardon, 2007). Ancient civilizations experimented with natural dye techniques and generated patterns on textiles in sustainable ways (Safford, 1968). In many parts of the world, natural dyeing is considered a ceremonial tradition that is still practiced in handicraft industries (Ranatunga et al., 2020). Natural dyes have many benefits to the wearer as well as the environment. Since they are derived from nature, they are recyclable, biodegradable, and decomposable (Alam et al., 2020). At the same time, since natural dyes do not contain any harmful chemicals, they are nontoxic and non-allergenic making them suitable for people of all ages (Alam et al., 2020).

Until the invention of synthetic dyes in 1856, textiles were dyed with natural dyes. Since then, the use of synthetic dyes has dominated the textile industry. Křížová (2015) states, "synthetic dyes were so successful that natural dyes currently account only for about one percent of the total amount of dyes used worldwide" (p. 2). The use of natural dyes has diminished over generations due to lack of documentation and precise knowledge of the extracting and dyeing techniques (Arora, 2017). However, natural dyes can produce special aesthetic qualities that are beneficial to the planet and its people. This ethical and environmentally friendly significance gives an added value to naturally dyed textiles and products as craftwork and as an industry (Doty et al., 2016; Kanchana et al., 2013).

Natural dyeing and craft industry in Sri Lanka

The traditional natural dye practice of Sri Lanka goes back more than 2500 years, and the knowledge has been passed down from generation to generation (Ranatunga et al., 2020). The earliest written record of the use of natural dyes in Sri Lanka dates to the 3rd century when tree barks and leaves were used to dye Buddhist robes (figure 1) (Wijayapala et al., 2019). The two known methods of dyeing robes were with tree tannin and milky sap, and mud dyeing (figure 2) (Ranatunga et al., 2020). The use of natural dyes can also be seen in frescoes: a method of painting water-based pigments on freshly applied plaster (Britannica, 2020), in the Sigiriya rock fortress (figure 3) dating back to the 5th century (Somathilake, 2007).

Figure 1

Dyeing of Buddhist Robe with Ironwood Tree Bark Chips

Figure 2

Mud Dyeing

Figure 3

Sigiriya Frescoes Drawn using Natural Dyes

Sri Lanka is well known for its beautiful crafts consisting of many products made of raw materials that are mostly derived from nature (The Island, 2021). In Sri Lanka, most of the village communities engage in traditional handicraft industries such as wood carving, brassware, silverware, ceramic, mat weaving, reed and rush ware, lace making (figure 4), textile weaving and batik dyeing (figure 5), and portray a strong connectivity between their livelihood and cultural traditions. The Sri Lankan handicrafts industry is highly labor intensive, cottage based and decentralized (Teo et al., 2020). In the past, many handicraft techniques used natural dyes (Wijayapala et al., 2008), however, in recent years most of the country's textile and craft industry has diverted to using synthetic dyes (Ranatunga et al., 2020).

Figure 4

Lace Making also known as Beeralu Lace Weaving, Bobbin Lace or Pillow Lace

Figure 5

Batik Prints

Coconut industry in Sri Lanka

Sri Lanka is an island located in the Indian Ocean, that has a tropical climate with wet and dry seasons. Sri Lanka is the fourth-largest exporter of coconut products to the world (*Coconuts &.*, n.d) and the second-largest land user for coconut in the world (Jayewardene, 2018). Coconuts are linked with the Sri Lankan culture and ethnicities of its people. Hence, it is used in many rituals, festivals, and food in daily life. Therefore, it has been inaugurated as "Kapruka" (tree of life) – a source of plenteous resources (*Introduction of coconut*, n.d). Each part of the coconut tree is used at an industrial scale and used in the craft sector to create various products such as food, delicacies, farm equipment, household items, roofing material, and furniture (Yogaratnam, 2011). In 2020, the export value of the Sri Lanka coconut industry was UD$650M and close to 80% of the 2700M nuts produced in 2020 were consumed locally (*Want to learn about*., n.d). Even though the coconut tree is used at an industrial scale and in the craft sector (Yogaratnam, 2011), the fibrous husk and shells that are used domestically are thrown away generating domestic waste (figure 6).

Figure 6

Coconut Husk Waste

Coconut husk dye

The fiber obtained from the outer layer of the fruit of coconut tree (Cocos nucifera) is called 'coconut husk' (Yogaratnam, 2011). Previous research on dye extraction methods, colorfastness, and color optimization techniques has indicated the fibrous husk can be used as a source of natural dyes for textiles (Adeel et al., 2020; Kashyap et al., 2016; Kholil et al., 2021; Sahara et al., 2019; Samant & Gaikwad, 2020). The initial extraction after boiling produces a brown color (Kholil et al., 2021) which can then be altered using various mordants to produce other shades such as cream with alum, greenish brown with ferrous sulfate, yellow with naphthol salt (Samant & Gaikward, 2020), dark salmon pink and clamshell pink with alum, muddy water brown with calcium carbonate (Sahara et al., 2019), and reddish-brown color under the influence of microwave treatment (Adeel et al., 2020).

Samant & Gaikwad (2020) suggests pre-soaking and ultra-sonification of the fiber prior to boiling improve production yield. Aluminum acetate was identified as the best mordant that showed better colorfastness properties against rubbing, soap washing, and sunlight exposure (Kashyap et al., 2016; Kholil et al., 2021). Apart from mineral mordants, bio-mordants such as henna, pomegranate, acacia bark and turmeric were found to improve the color strength and bond between fiber and dye (Adeel et al., 2020).

Surface Design Techniques

Dyeing and applying surface design to fabric can create unique colors and effects. The Surface Design Association defines surface design as, "the coloring, patterning, and structuring of fiber and fabric. This involves creative exploration of processes such as dyeing, painting, printing, stitching, embellishing, quilting, weaving, knitting, felting, and papermaking" (Miles &

Beattie, 2011, p. 2). The project explored a few easily taught and inexpensive surface design techniques.

Physical resist

Resists are treatments that prevent dye or paint from reaching and penetrating fabric, thus protecting the current color (Wada et al., 1999). Designs can be created by squeezing flat fabric into a three-dimensional form, which is then immersed in, dipped into, or painted with dye or discharge solution (Brackmann, 2006).

• Pole wrapping (*arashi* shibori) - Fabric is wrapped around a pole or a pipe and wound with yarn, string, or rubber bands. Then the fabric is pushed down to compress and resist before dipping into dye.

• Clamping (*itajime*) - Fabric is folded in two or more directions before clamping between paired blocks of shaped wood, acrylic, or plastic. The compressed fabric retains the original color while the projecting fabric takes up dye or discharge.

Block printing / Stamping

The process of printing on a fabric with a wood or linoleum block into which a design has been carved to raise the surface that gets coated with ink or paint. It is then pressed onto another material, leaving an impression of the design when pulled away (Corwin, 2008).

Dumbara weaving patterns

The inspiration for print development will be derived from the motifs created by Dumbara weaving (figure 7). Dumbara weaving is a technique used to make wall hangings, tapestries, and cushion covers by a community of traditional weavers living in the fertile Dumbara valley in the central highlands of Sri Lanka. Different types of motifs are woven on a floor loom using the fiber of the leaves of the hana plant (*Agave vera*) that are separated by hand, washed, sun-dried, and dyed (Doddamani & Senadheera, 2018).

Figure 7

Dumbara Patterns

Methodology

Gray and Malins (2004) state, “we learn most effectively by doing – by active experience, and reflection on that experience” (p. 1). The purpose of this study was to explore the dyeing potential and surface design possibilities of coconut (*Cocos nucifera*) husk fiber as a source of natural dye. This involved conducting experiments to gain dye and print knowledge, reflecting upon the results, and applying best practices to create textile designs. Hence, a practice-based research approach was used for this project.

Practice-based research is an original investigation undertaken to gain new knowledge partly by means of practice and the outcomes of that practice (Candy, 2006). Candy (2006) further states, “The primary focus of the research is to advance knowledge about practice, or to advance knowledge within practice” (p. 3). In this process the resulting creative artefact along with its creation process, becomes the basis of the contribution to knowledge. Skains (2018) says, “practice and research go together in various arts disciplines because the knowledge acquired from the creative practice process informs the critical explorations” (p. 85).

In practice-based research, the researcher’s insider knowledge, experience, and status provide credibility and trustworthiness to the research (Gray & Malins, 2004). Throughout my academic and professional career as a fashion and display designer, and an entrepreneur, I have experimented with different materials, techniques, and design concepts that gave me a great opportunity to learn new things. This knowledge and experience I gained through previous study, such as years of learning about design concepts, apparel design, textile dyeing, and foundations of sustainability, certainly benefited this project and served as a fundamental knowledge and experience base to draw upon. At the same time, living in England and now in the U.S., I have had the chance to experience the fashion industry and how it operates on a firsthand level and having worked in the industry back home in Sri Lanka, I have also had the experience on how differently things operate in developing countries where most of the outsourced production take place. Therefore, I have been on "both sides of the fence" which allowed me to draw upon my industry and academic experience and knowledge throughout this practice-based research.

The overall approach to this design research was to investigate the natural dye properties of coconut husk on various naturally fibered materials, explore surface design methods, and share the outcomes in an exhibition. The outline of methods is presented next, followed by the analysis that was ongoing to inform design decisions and future practice.

Methods

Stage One - Dye Experimentation

Materials

The main raw dyestuff used in this project was coconut husk waste, which was obtained from two households in Sri Lanka (figure 8). Thirteen fabrics were used to explore dye behavior on various fibers and weaves. The cellulose fibered fabrics were cotton sateen, cotton batiste, cotton print cloth, linen/cotton blend, hemp/cotton blend, bamboo rayon, and bamboo poplin. Silk fabric types were crepe de chine, silk habotai (12mm), heavy crepe, chiffon, silk noil, and organza. For sampling purposes, the fabrics were cut to 8" x 10" pieces and overlocked. I chose these fibers and fabrics because much clothing in Sri Lanka are produced using breathable fabrics such as cotton and linen because it is a tropical country. At the same time, silk is a popular choice for saree; an item of traditional clothing worn by women in the South Asian region. Even though wool takes natural dye better than most other textiles, it was not investigated in this research because wool is not a fiber that is commonly available in Sri Lanka.

The pre-treatments for cellulose fabrics were aluminum acetate dibasic (aluminum acetate), gallnut, pomegranate, and henna; for silk fabrics potassium aluminum sulfate dodecahydrate (alum). Ferrous sulfate and citric acid were also used as post-mordants to increase the color range.

Figure 8

Coconut Husk

Pretreatments

Cellulose fabrics weighing 770 g were scoured using 1% neutral detergent (7.7 ml) and 1% sodium carbonate (soda ash) (7.7 g) for two hours in 100 °C water. Fabric was left to cool and rinsed. Silk fabrics weighing 215 g were scoured using 1% neutral detergent (2.15 ml) for thirty minutes in 50 °C water. Fabrics were left to cool, rinsed and hang dried for a day.

When mordanting, I started with cellulose first because I decided to use four pre-mordant methods. The first step was the application of tannin. Cellulose fabrics were divided into four sets. For the first, second, and third sets I used gallnut extracts from Botanical colors, ground rind pomegranate from Maiwa (both at 10% WOF and 30:1 water ratio) and henna (20% WOF and 30:1 water ratio) in 50 °C warm water stirring every ten minutes for two hours (figure 9). All three sets received a second mordant of aluminum acetate (5% WOF) in separate baths in 50 °C warm water stirring every ten minutes for two hours and left for 24 hours before rinsing. The fourth set was mordanted only with aluminum acetate (5% WOF) in 50 °C warm water for two hours while stirring every ten minutes and was left for 24 hours in the mordant bath before rinsing (figure 10). Treated cotton fabrics were bagged and stored damp in a refrigerator until needed for dyeing.

Figure 9

Cellulose Tannin Application

Gallnut Tannin Pomegranante Tannin Henna Tannin

Figure 10

Cellulose Mordant with Alum Acetate

Figure 11

Cellulose Fabrics after Pretreatment

Silk fabrics were divided into two groups, with both sets pre-mordanted with potassium aluminum sulfate (15% WOF) in 60 °C warm water stirring every ten minutes for one hour, then rinsed (figure 12), bagged, and stored damp in a refrigerator until needed for dyeing. One of the two sets was also treated with henna (5% WOF) to experiment with a different color shade (figure 13).

Figure 12

Silk Mordant with Potassium Aluminum Sulfate

Figure 13

Silk Pre-Dyeing with Low Concentration of Henna

Figure 14

Silk Fabrics After Pretreatment

Dye Extraction

First, I washed the coconut husk thoroughly to remove dirt and left it to dry. To be able to visually analyze color variations and allow for some randomization, I created two dye baths. After the husks were fully dried, I weighed them and used 250g of husk with 15 liters of water in each dye pot and boiled for two hours to extract the dye (figure 15). While extracting the dye, I checked the color of the water every half an hour to determine how long it takes for the water to turn into a desired color (figure 16). After a darker color was achieved, the dye was left to cool and strained to get the natural dye solution. After straining I had 12 liters of liquid dye solution in both pots.

Figure 15

Dye Pots with Coconut Husks before Extracting the dye

Figure 16

Dye Extraction Time Frame

Dye Application

Before dye application, one of each fabric sample was kept aside. Therefore, only a total of 616g of cellulose and 143g of silks were immersion dyed. The two dye solutions were divided across four pots (6 liters of dye in each pot) and heated to 50 °C. I divided the fabrics according to the pretreatment type and carried out the dyeing process in three stages to let fabrics have enough space in the dye bath to move freely. During the first stage, the cellulose fabrics weighing 154g that were pretreated with aluminum acetate was divided into two and immersion dyed in two dye baths increasing the temperature up to 100 °C for one hour. The silk fabric set pretreated with alum weighing 71.5g was divided into two groups and immersion dyed in the remaining two baths increasing the temperature up to 70 °C for one hour. Then during the second and third stages, the cellulose fabric sets pretreated with gallnut, pomegranate, henna, and silk fabrics pre-dyed with henna were divided into two and dyed the same way as above (table 1). When the desired color was achieved, fabrics were moved to a stop bath with plain water of a similar temperature and heated for an hour. The samples were later rinsed and hang dried.

Based on calculations, there was approximately 125g dye in one dye bath to 77g cellulose and 35.75g silks. Thus, the weight of fiber (113g) to dyestuff (125g) was 90%.

Table 1

Dye Application Process Across Each Dye Pot

	Dye Pot 1 125g husk	***Dye Pot 2 125g husk***	***Dye Pot 3 125g husk***	***Dye Pot 4 125g husk***
Stage 1	A. Acetate Cellulose 77g 100 °C for one hour	A. Acetate Cellulose 77g 100 °C for one hour	P. Alum Silk 35.75g 70 °C for one hour	P. Alum Silk 35.75g 70 °C for one hour
Stage 2	Gallnut Cellulose 77g 100 °C for one hour	Gallnut Cellulose 77g 100 °C for one hour	Pomegranate Cellulose 77g 100 °C for one hour	Pomegranate Cellulose 77g 100 °C for one hour
Stage 3	Henna Cellulose 77g 100 °C for one hour	Henna Cellulose 77g 100 °C for one hour	P. Alum + Henna Silk 35.75g 70 °C for one hour	P. Alum + Henna Silk 35.75g 70 °C for one hour

Figure 17

Immersion Dyeing of Fabric Samples

Post treatment

To increase the color range, seven of the thirteen fabrics, had post treatments of iron and citric acid. The selection of fabrics is described in the next section. I cut half of each fabric and divided them into two small quarter swatches. Citric acid at 2% WOF was used on one of the quarter samples to lighten the color, and ferrous sulfate (iron) at 1% WOF was used on the other to darken the color as post mordanting treatment.

Results and Analysis

Stage One - Dye Experimentation

Table 2 shows the color results of the cellulose fabrics. All the fabrics dyed in a pink beige color except for the fabrics that were pretreated with henna which turned out to have a yellow cast or nude color. Table 3 shows the coloring results of the silk fabrics. Similar to cellulose, silk fabrics also dyed in a pink beige and the fabrics that were pre-dyed with henna were nude in color. The pink tint supports prior findings (Sahara et al., 2019) when using an aluminum mordant.

Table 2

Results of Cellulose Fabric Dyeing

Table 3

Results of Silk Fabric Dyeing

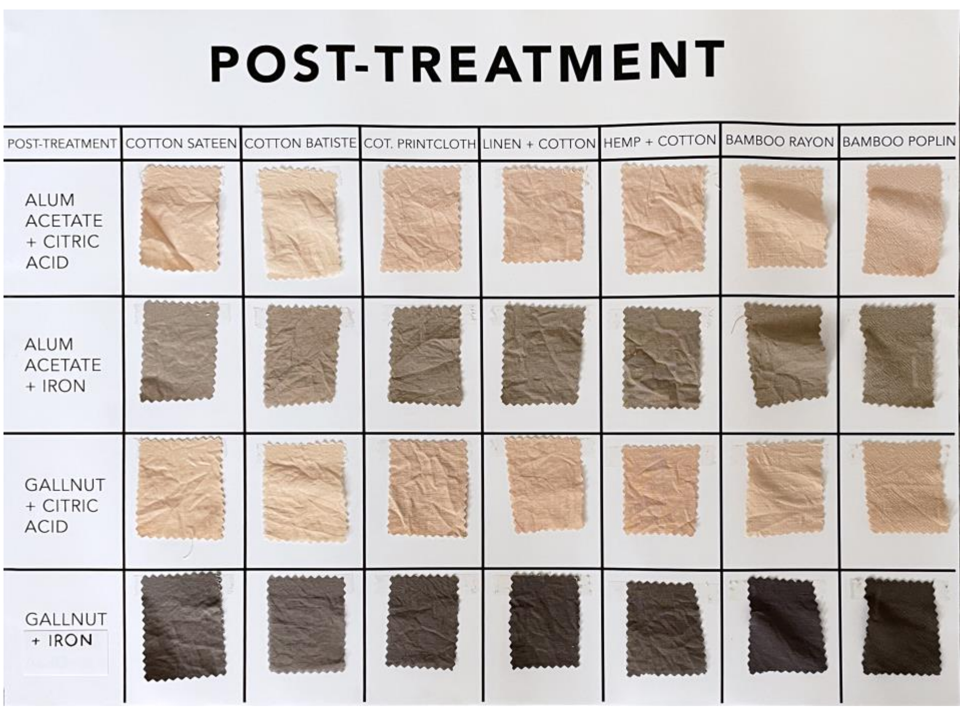
Based on the results that were achieved, a few important observations were made after visually examining the wide range of fabrics that were dyed using different pretreatment methods. The most critical finding was the slight hue variations, despite applying three tannin pretreatments with hopes of achieving shade variations. The swatches pretreated in aluminum acetate and pomegranate achieved the same color shade but, the swatches pretreated in gallnut were slightly darker in color shade. Prior research indicated that pomegranate may shift the hue towards green (Adeel et. al., 2020). Possible reasons for this lack of hue change could be due to cotton instead of wool as used in the Adeel (2020) research or the concentration of pomegranate used. Only the swatches pretreated with henna showed a clear change in color shade towards yellow. Meanwhile, the silk fabrics too appeared very similar in color intensity to the cellulose. Comparatively, some of the tightly woven fabrics such as linen, hemp, and heavy crepe had a slightly darker shade.

As a result, I concluded different pretreatment methods did not serve their purpose in contributing to color diversity. Pretreating cellulose with tannin is a two-step process. Thus, it requires more time, water use, and effort. However, since the tannin application didn't produce shade variation as I had hoped, I decided to move forward with only using aluminum acetate as a pretreatment for cellulose and potassium aluminum sulfate for silk. The thirteen textiles were reduced to cotton sateen, cotton batiste, and bamboo rayon for cellulose and crepe de chine, silk habotai, and heavy crepe for silks. These fabrics were selected based on their ease of use, variation of fabric weight, and appropriateness for future use in garment and saree design.

Based on the results of limited color variation from the initial dye experimentation, I decided to only use the swatches that were pretreated with aluminum acetate and gallnut for post treatment process. I chose gallnut over pomegranate and henna because gallnut swatches were slightly darker in shade. Therefore, I thought I might be able to achieve a visible variation between the two mordant types. Table 4 shows the coloring results after post treatment with citric acid and iron.

Table 4

Results of Post-Mordant with Citric Acid and Iron



The 1% WOF iron treatment was expected to darken the dyed swatches to a greyish brown (Sahara et al., 2019), instead, the iron-treated swatches had a greenish grey tone, more noticeably darker grey tone with gallnut pretreated swatches as the gallnut tannin reacted with the iron more than aluminum acetate. The 2% citric acid treatment turned the swatches to a pale orange shade. However, there was minimal color variation between the two different types of mordants.

In conclusion, all the selected fabrics performed well in the evenness of dye uptake and saturation between all the pre and post treatment methods. There was no color loss after hand washing indicating appropriate dye concentration and good dye to fiber bond. Due to minimal visible color variation of the tannin pretreatments, I concluded different pretreatment methods did not serve their purpose in contributing to color diversity. At the same time, the thirteen textiles were reduced to three types of cellulose and three types of silks based on their ease of use, variation of fabric weight, and appropriateness for future use in garment and saree design.

Stage Two – Print Design Exploration

Inspiration for print development was derived from traditional and modern Dumbara weaving patterns. Using a few designs, I formed a collage of visually impactful imagery to guide the process of creating patterns for surface prints (figure 18). The overall inspiration theme was geometrical shapes. Creation of designs that have a strong positive/negative space, and print quality were explored by experimenting with a few different types of print making techniques. This stage included making the dye paste and exploring surface design methods.

Figure 18

Dumbara Motif Inspiration

Making the dye paste

The first step was to recycle the coconut husk dye bath to separate the pigment from the water (Boutrup & Ellis, 2018). Alum (60 g) was added to 6 liters of dye bath to bind the dye particles. After stirring gently, 30 g soda ash was added to neutralize the bath and was left to precipitate. After the lake pigment settled at the bottom (figure 19), the pigment solution was strained through cotton batiste placed in a mesh strainer. After all the water was strained and the lake pigment turned into a pudding like texture, I mixed gum tragacanth print paste thickener (Botanical Colors, U.S.A.) to get the pigment to a correct consistency for printing.

Figure 19

Recycling the Dye Bath - Lake Pigment Settled at the Bottom

Block printing

The first print development technique I tried was blocking printing. I used Speedy Carve blocks and carved the selected designs to raise the surface (figure 20). Then the surface was coated with the thickened dye paste and pressed onto the fabric to test the impression of the design after pulling away.

Figure 20

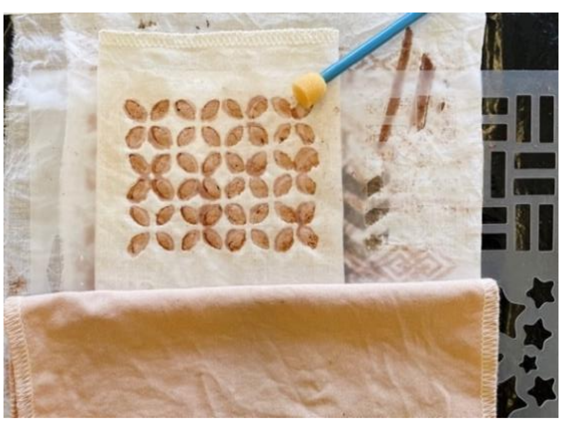
Carving Speedy Carve Blocks

Stencil printing

Next, I tried stencil printing. I used ready-made stencils that are laser cut on flexible thin acrylic sheets. The fabric was placed on a padded layer and the stencil was placed on top. I used a sponge to dab the thickened dye lake in between the openings of the pattern (Figure 21).

Figure 21

Stencil Printing



Screen-printing

The next method I tested was screen-printing. The screens were made by burning the design onto mesh using a thermofax machine. The patterns were generated in Adobe Illustrator and printed in greyscale on paper using a laser printer. Then the image was placed against the screen mesh and fed into the thermofax machine to burn the screen (figure 22). The screen was then taped around the pattern on to a plastic frame to control and create wells for the paste (figure 23). The thickened dye paste was poured into one side of the screen and the paste was drawn across the screen (figure 24). Printed samples were left to dry, and heat set with steam to bind the color to the fibers. I also mixed some iron to the thickened dye paste to experiment with achieving different color shades when printing.

Figure 22

Printing the Design on the Mesh using Thermofax Machine

Figure 23

Finished Screens

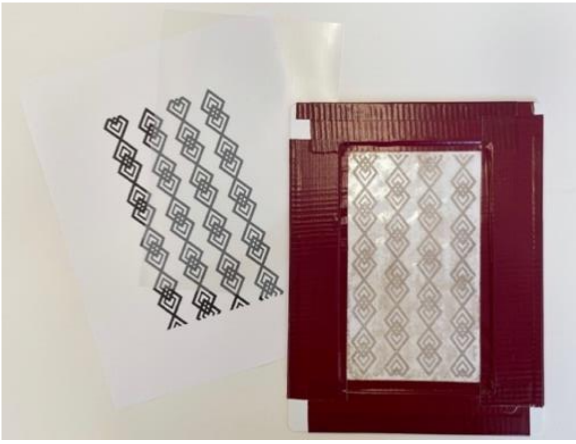


Figure 24

Screen-Printing the Pattern on to the Fabric

Physical resist

For the physical resist techniques, pole wrapping and folding and clamping were sampled. Based on prior experience, I decided to use lightly woven fabrics such as crepe de chine and organza to create lines using pole wrapping with hopes of creating 3D embossed textures after releasing the fabric. Cellulose fabrics were used for folding and clamping.

Results and Analysis

Stage Two – Print Design Exploration

Table 5 shows the results of print experiments made on a cellulose and silk fabric sample. The thickened dye paste did not attach well to the rubber block. Hence, the prints appeared smudged and left lumpy pigment particles on the fabric. The stencil didn't hold the dye paste well around the edges and appeared to be leaking underneath the uncut areas. Therefore, clear lines between patterns were not achieved. When comparing the three techniques, block printing and stencil printing patterns were not visually pleasing as compared to the screen-printing. The thickened dye paste consistency worked best with screen-printing leaving clear lines around the edges of the prints.

Table 5

Results of Print Experiments Using Block, Stencil, and Screen-Printing Methods

Cellulose Fabric	**Silk Fabric**
	

After analyzing and reflecting upon the results achieved in the print technique exploration stage, a few important decisions were made. As one of the objectives of the project was to explore inexpensive surface design techniques, block printing was the initial method I had in mind for print making. It is easily available in Sri Lanka because it is already an established craft industry in the country. However, based on the results, I realized that it didn't work for the current project. This could be because I made the blocks using rubber stamps and the consistency of the thickened dye paste was not appropriate to provide good results. But block printing would still be a viable option to further explore in the future to experiment with proper wooden blocks.

After discussing with my major professor, I decided to move forward with screen-printing to complete the project. Even though the technique is different, I was able to continue with the same print inspirations and patterns with good results (figures 25 and 26). Getting the screens made can be an expensive task at first. However, it is a quick and easy way to make distinct patterns on fabric. Besides, the screens can be used many times repeatedly. By integrating physical resist patterns and screen-printing, as well as combining iron to the dye paste, I was able to explore different patterns, color shades, and create a visual sense of depth with foreground and background prints (figures 27, 28, and 29).

Figure 25

Results of Screen-Printing on Dyed Bamboo Rayon Fabric

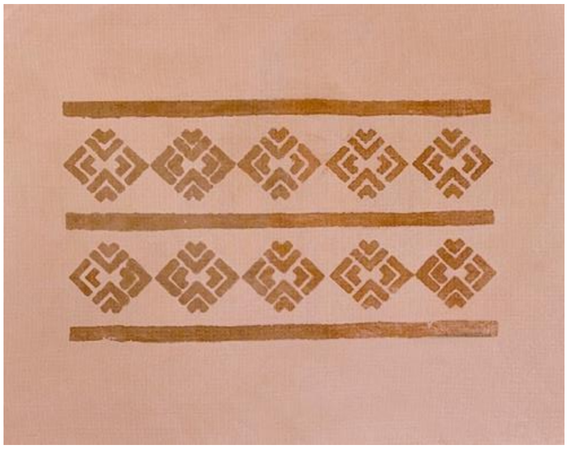


Figure 26

Results of screen-printing on undyed but pretreated silk habotai

Figure 27

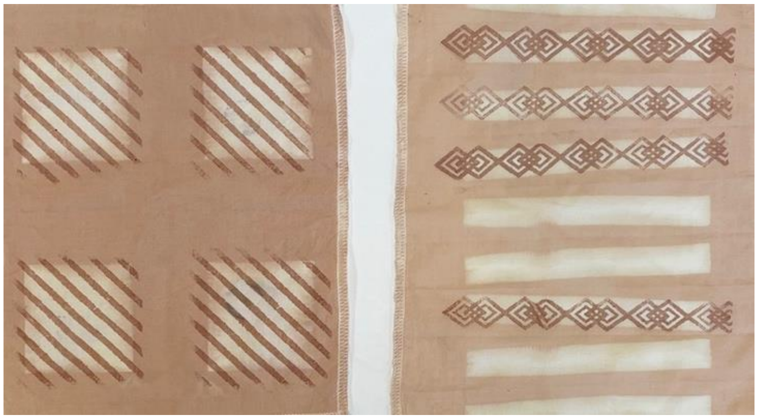
Results of Screen-Printing with Iron Mix Dye Paste

Figure 28

Results of Pole Wrapping and Screen-Printing on Silk

Figure 29

Results of Folding and Clamping with Screen-Printing on Cellulose



Artifact Development, Results and Analysis

Through sampling, documenting, evaluating, and reflecting on the data that evolved throughout the first two stages of the practice-based research, I was able to make decisions regarding the best practices to move forward in developing the final textiles for the exhibition. One of the most important factors to mention is while proceeding further I realized that I am designing with limited expertise on natural dyeing large scale fabrics and screen-printing with dye paste. Therefore, I knew I had to edit designs and make changes to techniques at the most unexpected times. When challenges and unexpected events emerged during the process, I had to reflect upon the results and notes from previous stages and do more research to troubleshoot while developing the final artifacts. This cyclical versus linear process is often noted in practice-based research (Chen & Lapolla, 2020; Hahn, 2020). Therefore, in this section I have presented the methods, results, and analysis together.

One of the biggest challenges I faced at an early stage when dyeing the textiles was that I realized some of them had patchy areas after dyeing. With previous knowledge and experience I had from a textile surface manipulation class, I understood that this was most likely due to an uneven attachment of the mordant to the textile. Thus, after discussing with my major professor, I decided to mordant the fabrics again. This process presented much better results.

On the other hand, after the first fabric was dyed, I realized it was browner in color tone than what I had achieved previously during the first stage of experiments. Therefore, before I dyed the rest of the textiles, I decided to make another dye bath and test the color by dyeing smaller samples. Visible color variation was confirmed between the new samples and the samples I dyed during the first stage of the research (table 6). Most of the new fabric samples had a brown tone or a darker value compared to the pink beige I initially achieved. Then I reflected upon the dye making process to figure out if something went wrong.

Table 6

Color Variation of Dye Samples

First stage dye bath samples	**Final stage dye bath samples**
	

After talking with my mother who sent me the coconut husks from Sri Lanka, I realized the husks I used for the first stage of dye experimentation was from old and mature coconuts that was sent to me a few months back and the coconut husks I used to dye the final textiles were from new coconuts because they were sent to me recently. At the same time, I was informed that only some of the husks were from the coconut trees in my parents' backyard and the others are from my uncles' backyard who lives in a different city. This made me compare the color of the new husks with the photo I had of the husks I used during the first stage, and I realized the new husks are much lighter in color (table 7). Previous research also indicated that fresh husks contain more tannin than old husks (Emojevwe, 2013) which could yield a darker hue. At the same time, the shade of the color a plant produces can vary according to time of the year the plant is picked, how it was grown, soil conditions, and various other reasons (Vankar, 2000).

Table 7

Color Comparison of the Old and New Husks

Old coconut husks	**New coconut husks**
	

This information was enlightening and educational for me because the color palette during the first stage of dye experimentation was not diverse in color variation, but this new finding informed me of new possibilities of color varieties to work with. I decided this will be a positive aspect when I complete the final artifacts. At the same time, this could also be an interesting topic to research further in future studies.

Design and Print Development

This section covers the decisions made during the design and print development stage for the final artifacts from technique applications, design adjustment and challenge, to finished product. At most instances, the print designs and layout were created by imagining how the final textile would serve the purpose of turning into a garment in the future. Based on the finding that the age of the husk produced different shades, I decided to play with color variations by dyeing textiles separately in different baths.

The first textile was made with an ombre effect to show how to achieve various color shades depending on the time the textiles were left in the dye bath (figure 30). The fabrics was dyed using the dye bath made of new husks. The fabric was moved at 10 minute intervals with a time frame extending from 10 minutes for the lightest color to 60 minutes to darkest color.

Figure 30

Design One - Ombre Textile

Design two was made on silk crepe de chine. The fabric was first dyed in the dye bath made of old husks with fold and clamp technique to make white squares that can be later printed on. After the fabric was dried, I printed the patterns inside the white squares which were bordered by the dyed stripes (figure 31). Even though I secured the wooden squares tightly, I realized some dyes slightly seeped into the white squares and the grains and stain or finish on the wood left a mark on some areas. For the future, I would recommend using acrylic squares instead of wood or covering the wooden pieces or using the same size acrylic sheets in between the fabric and wood to make sure it won't leave any marks. At the same time, securing the resist from the middle will also help with limiting the color leaking to the inner areas as I only used clamps on the four corners.

Figure 31

Design Two – Silk Crepe De Chine with Fold and Clamp Resist, then Screen-Printed

The third design was created in silk habotai and was challenging because I wanted to create vertical lines on the fabric by pole wrapping. However, the fabric was too wide for the poles that were available in the dye lab. So, I decided to change the design by cutting narrow panels that were wrapped separately. I divided the fabric into three panels and only used two panels for pole wrapping. The fabrics were dyed in the old husk bath to achieve a pink shade.

After drying, all the three panels were sewn together (figure 32). Design four was based on a suggestion from a colleague to create the same design in the brown shade. I followed the same steps as the previous design but used a crepe de chine that was dyed in the dye bath made of new husks. This fabric has four panels that are attached together with two panels having the stripe designs (figure 33).

Figure 32

Design Three – Pole Wrapped Silk Habotai in Pink Shade

Figure 33

Design Four – Pole Wrapped Crepe De Chine in Brown Shade

The fifth design was made on a cotton sateen imagining it to be used to construct a pant or a skirt in the future. Therefore, I made the prints with intention on how it would look like after the garment is made. The fabric was immersed completely in the old husk dye bath and the screen-prints were made horizontally towards the bottom of the fabric. I mixed the prints with the dye paste that was darkened with iron to break the monotony (figure 34).

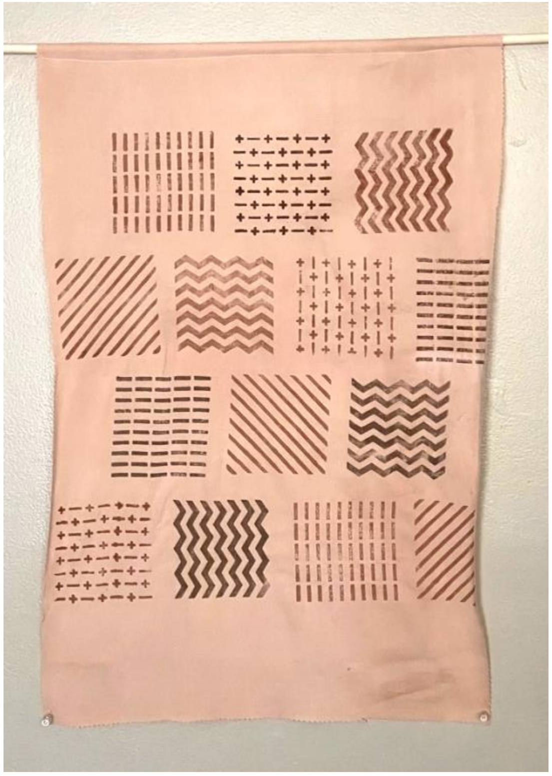
Figure 34

Design Five – Cotton Sateen with Horizontal Print Design

The sixth design was an attempt to recreate one of my favorite Dumbara weaving patterns. I used a bamboo rayon fabric and immersion dyed it in the old husk bath. The design layout that consisted of several geometric patterns which were screen-printed as a mix and match overall print. I used the darkened print paste to add color variations (figure 35).

Figure 35

Design Six – Mix and Match Overall Print on Bamboo Rayon



The seventh design was created on a silk habotai to mix pole wrapping and screen-printing. As mentioned earlier, I had to cut the fabric into narrow pieces to be able to wrap around the pole. First, I immersion dyed the entire fabric in a light shade in the old husk bath. This fabric was pole wrapped and dyed again in the old husk bath for a longer period of time hoping to achieve a darker shade of lines compared to the solid color. But I was not able to achieve distinctive color variation. This could be due to reusing the same dye bath, thus not having the dye concentration needed for a darker shade. Therefore, I left the other two panels in plain color and made a repetitive design using screen-print (figure 36).

Figure 36

Design Seven – Pole Wrap and Print on Silk Habotai

Even though I faced many challenges along the way and had to make changes to some of the initial designs I had in mind, overall, I believe the outcomes were satisfactory. Out of resist dyeing techniques, pole wrapping gave the best results. However, better results could be achieved by the fold and clamp technique by figuring out the best material to use as the resist. Meanwhile, the square screen-print patterns were easier to maneuver and were flexible to print in multiple directions providing many layout options. For future research, I would recommend having a dye bath with a higher concentration of dye to the weight of fiber to achieve hue variations in the designs.

Exposition

As the final stage in this practice-based research, the outcomes of the first three stages along with information about the process were showcased at the William T. Kemper Gallery in the student union of Kansas State University from April 11th – 23rd, 2022 in the form of an exposition. An exhibition displays a body of work for public appreciation (Gary & Malins, 2004). However, an exposition reveals the stages of design thinking and evolvement of the research process (Douglas, 1997). One of the overarching long-term goals of this project was to create awareness and educate the public regarding the use of natural dyes to minimize the environmental footprint in the fashion industry. Therefore, I chose an exposition over an exhibition because while showcasing the research outcomes, I was able to provide informative background information and photographs of each process, design thinking, and new findings for the public to gain first-hand knowledge of my research. Meanwhile, the exposition served in promoting public recognition and appreciation for the long process of natural dyeing in an effective manner.

Overall, the exposition was installed by strategically arranging the display objects and posters to portray the three stages of the research project. One of the biggest challenges was to determine the appropriate amount of information to share with the public who are less knowledgeable in the subject. Although not all aspects of the research were presented, the key components of the process, techniques, decisions, and results were well illustrated using written information, photographs, samples of the progression of the experiments, materials, and equipment that were used.

The gallery was a rectangular space with three blank walls and a central pillar. The front had two entrances. I placed the title of the project at the beginning of the right-side entrance to allow a rotation of an anti-clockwise direction through the space. The first wall on the right side included five 18” x 24” posters that provided information on the project background and two display boxes that exhibited examples of coconut husks, dye extraction, dyed and undyed fabric samples, and dyed yarns (figure 37). Towards the second half of the wall was the information regarding dye extraction and results (figure 38). Three wall-mounted charts including fabric swatches presented the coloring results of cellulose and silk dyeing and the post-treatment processes.

Figure 37

Right-Side Wall with Background Information and Stage One Results

Figure 38

Stage One Results

Content of the center back wall included the process and results of the print design exploration. Two information posters and two display boxes showed the process while sixteen 11”x14” picture mats were used to mount and frame the fabric samples for display (figure 39). The wall on the left side included information regarding artifact development and interesting findings such as how different coconut husks produced different color shades. Three large textile samples were displayed along the wall. I arranged a center display in the middle of the gallery space by hanging four textiles in different angles and heights (figure 40). Three dress forms were used to drape some of the textiles to depict a look of a garment (figure 41).

Figure 39

Center Wall with Stage Two – Print Exploration

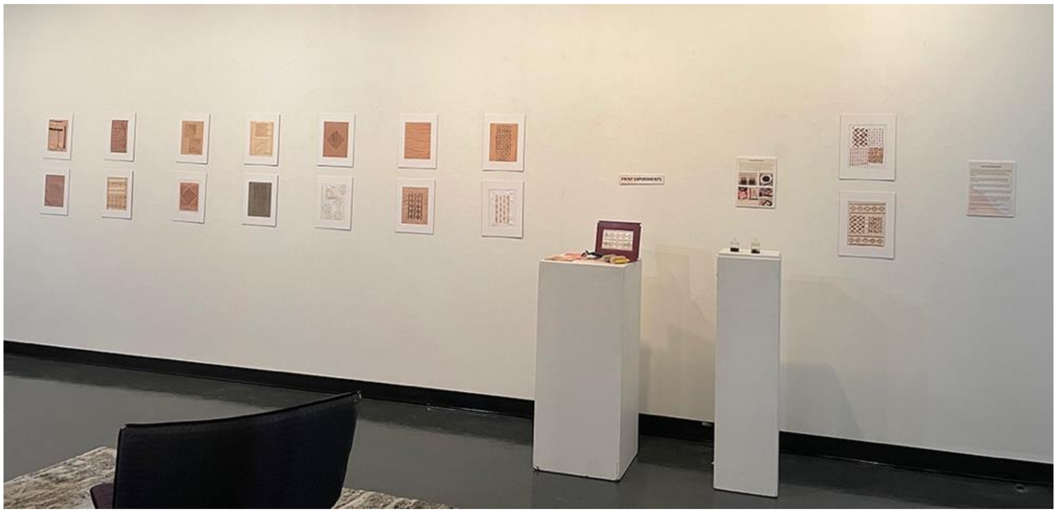


Figure 40

Center Display

Figure 41

Dress Forms with Draped Textiles

Results and Analysis

The exposition meant to promote and educate the public regarding the use of coconut husks to create natural dyes and the use of natural dyes in the fashion industry in general. When reviewing the exposition and based on the comments I received, I found that the written statements on the design process and results, along with samples and final textiles were effective in communicating the research purpose, process, and outcome in an easily comprehensible manner.

"The explanations of your process were very interesting. A very nice presentation"

"What a great learning experience in color. Nice explanation of your work"

"Eco-dyeing is something I only recently have experimented with. The process is just as important as the final product. I'm so thankful for you showcasing that"

Similar to myself, most people were intrigued by the final colors that were achieved from coconut husks and the idea that maturity level of the coconuts can produce different colors and shades. From personal experience I know, dyeing with natural materials is a very labor intensive and time-consuming task which results in much higher price points in retail compared to synthetic dyed garments. Therefore, I intended this project would help express the complex process of natural dyeing in an effective way. I believe the exposition served its purpose in promoting public recognition and developing public knowledge about the use of coconut husks to produce natural dyes and about the time and effort put into the process of natural dyeing. At the same time, based on the comments received by some of the undergraduate students in the fashion studies program, this exposition generated inspiration and provided them with future design and research possibilities.

"Love the beautiful rose color of the fabrics and how you talked about natural dye techniques in Sri Lanka"

"Very interesting to see all the shades of pink and the trials done. It is so encouraging to see sustainability"

"Couldn't imagine how much work and effort you put into these works. Reflects hard work and creativity"

"So beautiful and creative while appreciating your culture"

Reflection and Recommendations

The purpose of this study was to explore the dyeing potential and surface design possibilities of coconut (*Cocos nucifera*) husk fiber as a source of natural dye. It is one step toward my overarching aim to incorporate sustainable design methods to the traditional craft industry in Sri Lanka and to minimize the environmental footprint in the fashion industry and to shift my fashion brand to a sustainable brand. Although I had some experience in working with natural dyes by undertaking previous projects and experiments, this project has provided me with rich information that strengthened my knowledge of working with natural dyes, print design techniques, and various possibilities of conducting research using one dyestuff. At the same time, as the fundamental process of practice-based research is to learn through active participation and reflection on the experience (Gray & Malins, 2004), this project assisted me with understanding how to overcome challenges by practicing and reflecting upon the process to find new solutions to move forward.

As discussed, the range of color from coconut husk and tannin pretreatments had minimal variation in dye experimentation stage. The colors achieved were pink beige, and nude which were very light in hue value. This could be due to the lower concentration of the dye. I recommend increasing the amount of husk to weight of fiber to see if a higher concentration of dye would achieve a darker shade. At the same time, future research could investigate higher concentrations of tannin, mixing the tannin with the husk dye, or using tannin as a post-treatment. However, the findings and final outcomes have further solidified my confidence in working with natural dyes and have inspired me to experiment with various other dyeing techniques and waste materials in the future.

Even though I have experimented with many eco-printing and physical resist techniques in the past, until this study, I have not worked with screen-printing before. Thus, this project has provided me with an alternative option for making surface design prints. However, I would suggest exploring different dye paste consistencies to achieve clearer and well-defined prints. This design research contributes to the knowledge base of natural dyes and printmaking with thickened natural dyes. For this research, I used gum tragacanth print paste thickener from Botanical Colors. I believe it would be worth exploring other types of print paste thickeners to get the correct dye paste consistency according to the chosen printing technique.

Overall, I realized, documentation of each process and the progression of the experiments through writing, photography, and videography allowed me to look back and reflect on what I did to gain valuable insights to improve the quality of my work. This was also useful when new findings occurred unexpectedly because I had previous information to compare. I was able to resolve many issues such as selecting the best fabrics to work with and overcoming issues faced when mordanting large fabrics by reflecting on previous knowledge and experience I had from undertaking other natural dye projects and the textile surface manipulation class. Discussions I had with my major professor allowed me to discover suitable solutions for new ways of doing things and allowed me to thoroughly reconsider some of the techniques further to strengthen the design process to achieve the final results. Gray and Malins (2004) describe this process as "reflection-in-action" where practitioners think about what they are doing and reshape the action while doing it (p. 22). This provides credibility and trustworthiness to the research because it is the researchers own practice that is reflected upon (Gray & Malins, 2004).

Even though I had to make changes to some of the initial plans I had, the outcomes of this research fulfilled most of my initial objectives and intentions in a satisfying way.

Throughout the stage of artifact development, many challenges emerged where I had to adjust the techniques and change the designs to resolve them. However, these changes and the accidental findings contributed in a positive way and provided many possible research options that can be explored in the future. Schön (1983) describe this as "design as a reflective conversation with the situation".

> A designer makes things. He works in particular situations, uses particular materials, and employs a distinctive medium and language. Typically, his making process is complex. Because of this complexity, the designer's moves tend, happily or unhappily, to produce consequences other than those intended. When this happens, the designer may take account of the unintended changes he has made in the situation by forming new appreciations and understandings and by making new moves. He shapes the situation, in accordance with his initial appreciation of it, the situation "talks back," and he responds to the situation's back-talk (p. 78).

Positive results achieved with aluminum acetate and potassium aluminum sulfate as mordants were a pivotal aspect of the research when reintroducing the craft of natural dyeing in Sri Lanka, because they both are chemicals that are available in the country. Even though screen-printing can be an expensive task at first, it can still be a feasible option because of its ease of teaching and fast results. However, I would recommend researching further on using wooden blocks by experimenting with different consistency of the dye paste. With further practice, I believe good results can be achieved with blocking printing with natural dye paste. At the same time, it would be worth exploring using natural dyes on other traditional print making techniques such as batik and tie dye.

Sri Lankan craft industry has many sectors such as batik, handloom, weaving, and lace making that are fashion and textile based where natural dyes can be easily incorporated. In the past, I have worked with many local artisans where I have gained valuable connections for future collaborations. At the same time, after seeing the information regarding my research project, I was contacted by one of the fairtrade handloom weaving company that engages the traditional Sri Lankan community of handloom weavers who are interested in collaborating on a sustainable project. I believe this would greatly benefit my future aspirations of working with local artisans to provide them with the opportunities to grow and help the Sri Lankan fashion and craft industry be more sustainable in the future.

I believe this design research will be of interest to dyers and textile designers especially in locations where domestic coconut waste is abundant. There are many possible research options such as comparing color variations between old and young coconuts, coconuts from different geographical locations, and using different mordants that are native to the country. Therefore, it can be hoped that the design products from this project may inspire others in the field to work with natural dyes and the consumers to buy products made of sustainable design techniques.

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